

# The FAME Mission: An Adventure in Celestial Astrometric Precision

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**Abstract**—The Full-sky Astrometric Mapping Explorer (FAME) is a MIDEX class NASA Explorer mission that will perform an all-sky, astrometric survey with unprecedented accuracy. FAME will produce an astrometric catalog of 40 million stars between 5th and 15th magnitude. For the bright stars (5th to 9th magnitude) FAME will determine positions and parallaxes accurate to better than 50 microarcseconds, with proper motion errors less than 50 microarcseconds per year. For the fainter stars (between 9th and 15th magnitude) FAME will determine positions and parallaxes accurate to better than 500 microarcseconds, with proper motion errors less than 500 microarcseconds per year. FAME will also collect photometric data on these 40 million stars in four Sloan Digital Sky Survey colors.

The FAME science, instrument, and spacecraft requirements and error budgets are being refined to establish the basis for the improved design of the instrument and spacecraft. The Attitude Control System (ACS) based on solar radiation pressure is being studied, including the limitations on the solar angle between the Sun and the rotation angle. The data processing plans are being developed. The CCD procurement contract is in place and design and fabrication of the CCDs is in progress. CCD tests for operations in various Time Delay Integration (TDI) situations are underway and described in another poster. Launch of the FAME spacecraft is scheduled for Oct. 2004

This mission will be described in detail as well as its contributions to astrophysics and space navigation

## I. INTRODUCTION

The Full-sky Astrometric Mapping Explorer (FAME) will map the positions of 40 million stars to unprecedented accuracy. It consists of a large focal plane array of Charge Couple Devices (CCDs) similar to those found in video cameras that will scan the sky over a five year period. The accuracy of the measurements will exceed that of previous catalogs of star positions by an order of magnitude. These measurements will answer many fundamental questions in astronomy such as, What is the size of the universe? How many nearby stars have massive planets? How do stars evolve? How much dark invisible matter is in the halo of our galaxy? As well as form a basis for precise space navigation and determine the location of objects on the Earth's surface.

## II. BACKGROUND

Since the beginning of recorded time, man has sought to navigate on the Earth's surface using celestial bodies. The South Seas navigators used the latitude of stars to sail along the Earth's lines of latitude to locate islands in the Pacific Ocean. Sextants were developed to measure precise altitudes of celestial objects. Precise clocks were developed in order to determine longitude. The recent book "Longitude" by

Dava Sobel describes John Harrison's development of a clock that was accurate to about a second a month. This made precise chronometer an integral part of a ships navigation tools in the 18th century.

Today we rely heavily on the GPS satellites to give us our position on the Earth's surface. Four satellites can determine our position to within the accuracy of our knowledge of the positions of the satellites and their clocks via the time of arrival of their radio transmissions as received at the position in question. For precise positioning, knowledge of the satellites position is needed at the sub meter level and of the clocks at the nanosecond level as well as the time travel of the emission. However star positions are still used for precise geopositioning of objects on the Earth's surface. Today star positions are known at the sub-arcsecond level, such that if there were a sextant available at this accuracy, positions at the 30-meter level could be achieved. Further given precise star positions at the microarcsecond level, we could use them as a quasi-inertial reference frame to navigate in space at meter accuracies.

## III. ASTROMETRY

Astrometry is the science of measuring the position of objects in space. Positions of stars are defined in the celestial coordinates of right ascension and declination, similar to longitude and latitude. Distances to stars are defined as parallax. This is the semi-major axis of the ellipse in the stars apparent position resulting from the Earth's revolution around the Sun. Finally stars have independent motions in space defined as proper motion in right ascension and declination. Precise positions of stars in space are defined by these five parameters.

Fig. 1 shows the progress man has made in astrometry.

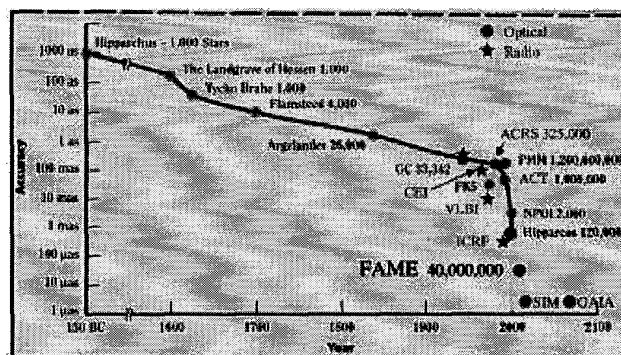


Fig. 1. Historical Development of Astrometry.

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The accuracy evolved from several degrees in ancient times when precession was discovered to the 17<sup>th</sup> and 18<sup>th</sup> century when the telescope allowed discovery of stellar aberration. In the 19<sup>th</sup> century, the first measurements of stellar parallax were made as accuracy reached below an arcsecond.

The Earth's atmosphere distorts the light from stars and until recently (before adaptive optics) the angular resolution of telescopes was limited to about an arcsecond, that of a 10 cm aperture. This limited the accuracy of precise astrometric measurements over large angles (>30 degrees) to 0.1 arcseconds using transit circle telescopes.

#### IV. SPACE ASTROMETRY

Obviously, if measurements are made above the Earth's atmosphere, this limitation can be overcome. There are two ways that one can proceed. A survey of a large number of stars can be made with a telescope that scans the sky at a uniform rate or one could stare at individual star fields. Both methods require that stars be linked together over angular distances. The survey instrument accomplishes this by viewing two fields of view simultaneously separated by about but not exactly 90 degrees. In using a staring telescope, one links stars by sequential observation or simultaneous measurements.

The Hipparcos survey mission of the European Space Agency launched in 1989 has successfully mapped the 100,000 brightest stars with a median precision of one milliarcsecond in position, parallax and proper motion. This is two orders of magnitude improvement over previous ground based measurements.

#### V. THE FAME SPACE MISSION

The FAME mission maps the Galaxy using a telescope with two fields of view separated by about 82 degrees. These two fields of view will be imaged on a focal plane array of twenty-four CCD devices that contain 4096 by 2048 pixels. The telescope will rotate with a period of 40 minutes and precess with a period of 20 days. It will precess around a cone angle of 45 degrees defined by the angle between the observatory rotation axis and the sun. The geometry of the telescope rotation with respect to the rotation axis and the Sun is shown in Fig 2. The Observatory will be in a near

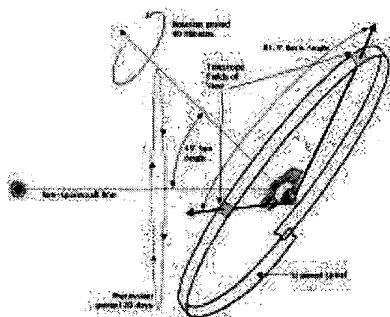


Fig. 2. Geometrical configuration of the FAME mission. The rotation axis of the satellite is set to 45 degrees with respect to the sun.

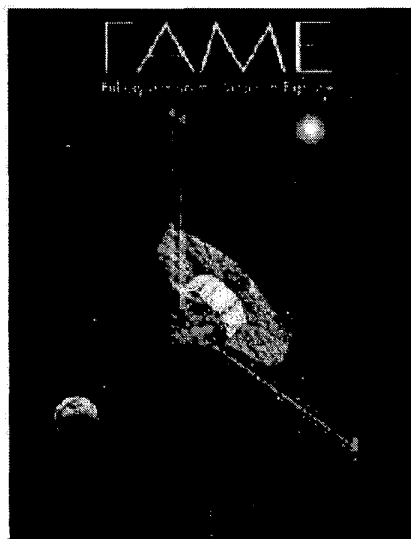


Fig. 3. Fame Observatory concept. Solar radiation pressure on the sun shield causes the rotation axis of the satellite to precess with a twenty day period.

geosynchronous orbit allowing for a single ground station at Blossom Point, Maryland. The FAME Observatory concept is displayed in Fig 3. The mission is a NASA Medium Class Explorer (MIDEX) and is a cooperative project of the US Naval Observatory, the Naval Research Laboratory, Lockheed Martin ATC and the Smithsonian Astrophysical Observatory.

Since the orbit of the Observatory is around the Earth, the Observatory's rotation/precession traces out a path on the sky that is best-displayed in ecliptic coordinates. The pattern of sky coverage is shown in Fig. 4. The measurement accuracy is not uniform over the sky. The accuracy of parallax is shown in Fig. 5. It is a function of the accuracy of a single measurement which depends on the telescope aperture size, the integration time, etc and the number of times the star has been observed at different orientation angles.

The accuracies shown in Fig. 5 will allow the position of stars to be measured to distances of 2 kpc ( a parsec is equal to 3.27 light years) to 10% accuracy as shown in Figure 4. This covers a very large area of the galaxy and will allow the determination of many fundamental parameters for stars. Knowing the distances to stars allow their absolute luminosity to be determined. The dimensions of the universe

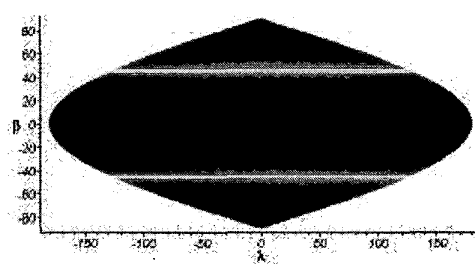


Fig. 4. Observation density distribution in ecliptic coordinates. The number of observations on the equator is at a minimum.

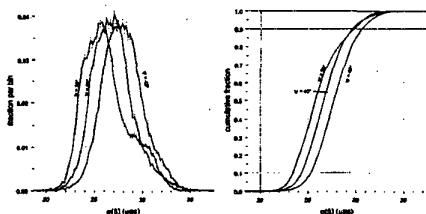


Fig. 5. Histograms of parallax errors (fraction in each bin).  
Left: Histograms. (Error bars are  $1\sigma$ , assuming Poisson statistics for each bin.)  
Right: Cumulative histograms.

are determined by measurements of "standard candle" stars in the galaxy, which calibrate the distances to nearby galaxies. The accuracy of this can be extended from about 10% to 1% by precise determination of the luminosities of these "standard candles." Massive objects (more massive than ten times Jupiter) revolving around nearby stars will be detected allowing reliable statistics of the presence of massive planetary objects around stars as thousands of stars will be surveyed.

The precise knowledge of star positions at the milli and microarcsecond levels allows the precise position and orientation of satellites via the almost inertial reference frame defined by the stars. With the positions of stars precisely known, the motion of a spacecraft will result in an apparent

motion of the star from which the spacecraft's motion may be determined.

The FAME mission in August 2001 is in Phase B of its development. In this phase the concept will be evaluated to meet the requirements of the mission. The cost, schedule and mass determined in Phase B to meet these requirements will alter the details of the original concept as the FAME team faces the reality of fabricating the Observatory. The cost of the mission may require that fewer than twenty-four CCDs are in the focal plane and that the angle between the Observatory axis of rotation and the sun be reduced to 35 degrees, resulting in a much smaller and cheaper sun shield.

## VI. CONCLUSION

Figs. 1 and 6 place the accuracy to be achieved by the FAME mission in perspective. It will be followed by NASA's Space Interferometry Mission (SIM) and ESA's Global Astrometric Interferometer for Astrophysics (GAIA). At the dawn of the 21<sup>st</sup> century, the precision with which the positions that star positions can be measured has improved by five orders of magnitude. This achievement will result in improved knowledge of the universe as well as improving man's ability to measure positions on the Earth's surface and precisely navigate in space.

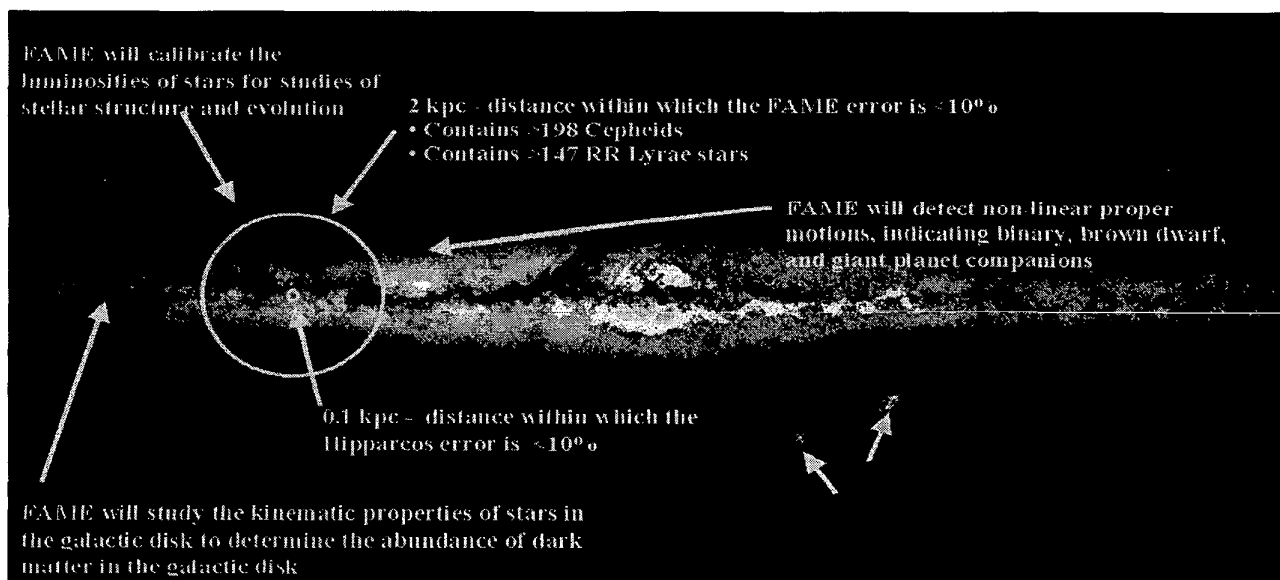


Fig. 6. The density distribution of stars in the galaxy is displayed. The arrow points to the location of the sun. The very small circle displays the distance from the sun at which the distance to stars were measured to 10% accuracy. This is representative of the Hipparcos mission. The large circle shows the distance at which FAME will measure the distances to stars 10% accuracy.